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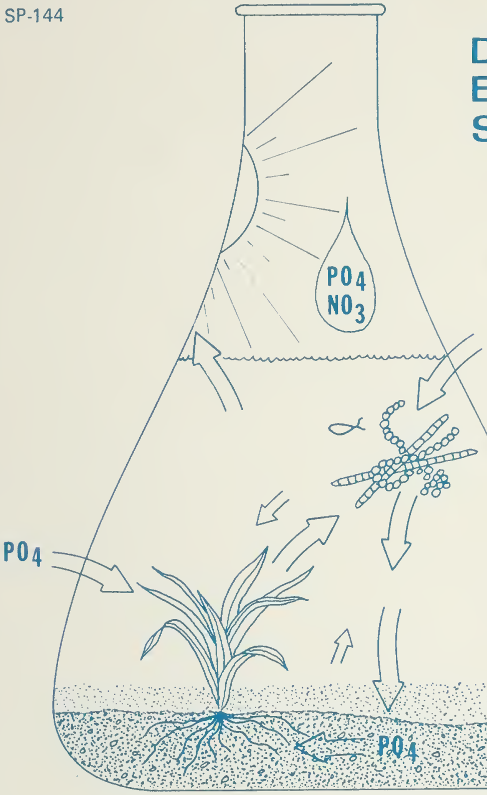

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LAKE MANAGEMENT NUTRIENT BUDGET

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LAKE MANAGEMENT
NUTRIENT BUDGET OF BEAVER LAKE

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This brochure provides a brief, non-technical overview of the rationale for lake management practices. As an illustration it summarizes one such study in which a team of researchers from the University of Massachusetts at Amherst investigated a eutrophying lake and recommended certain lake management practices over others.

INTRODUCTION

What is Happening in our Lake?

The initial awareness that something is wrong with a lake may take different forms, depending on how people use the lake. Boaters become irritated that an ever increasing portion of the lake has become inaccessible. Swimmers are annoyed by the luxuriant growth of "seaweed" which also leads fishermen to complain about tangled lines, fouled propellors, and decreasing catches. The once gravel shoreline has been transformed to a deep ooze. All of these symptoms suggest a sort of rampant fertility. Once the situation deteriorates beyond some undefined tolerance threshold, people start to ask what can be done. Several strategies may be employed to retard this aging process, depending on the cost and source of the problem:

SOME MAJOR LAKE MANAGEMENT PRACTICES, MODES OF ACTION, AND APPROXIMATE COSTS

I. EXTERNAL

	PRACTICE	MODE OF ACTION	∿ COST
1.	Zoning - Septic tank placement and design, lot size and frontage, construction practices, green belts.	prevents runoff and leaching of nutrients	unavailable
2.	Regulatory controls - discharge of laundry waters, shampooing in lake, fertilizing lawns, runoff from farms.	prevents runoff and other means of nutrients reaching the lake.	unavailable
II.	INTERNAL		
1.	Biological control - snails, crayfish, etc.	feed on plants	\$60/acre
2.	Bottom sealers - fiberglass screening (sheeting and sand ineffective).	prevents nutrient release to water column, and isolates rooting plants.	\$7000/acre
3.	Dredging	Limit light, and make turnover more difficult.	\$5.00/m^3
4.	Harvesting	Physically remove plants and phosphorous.	\$100-150/acre
5.	Herbicides	Poisons, plants and algae (plant growth) regulators).	\$100-150/acre
6.	Lake Drawdown	Plant of littoral zone subjected to winter freezing. Deepends lake-limits light and turnover in future.	
7.	Nutrient Inactivation, Flyash, Alum, Clay, aeration	Sediments out water column nutrients. Binds them in sediment surface.	\$250/acre
8.	Surface Shading	Limits light.	\$75/acre

LAKE DYNAMICS

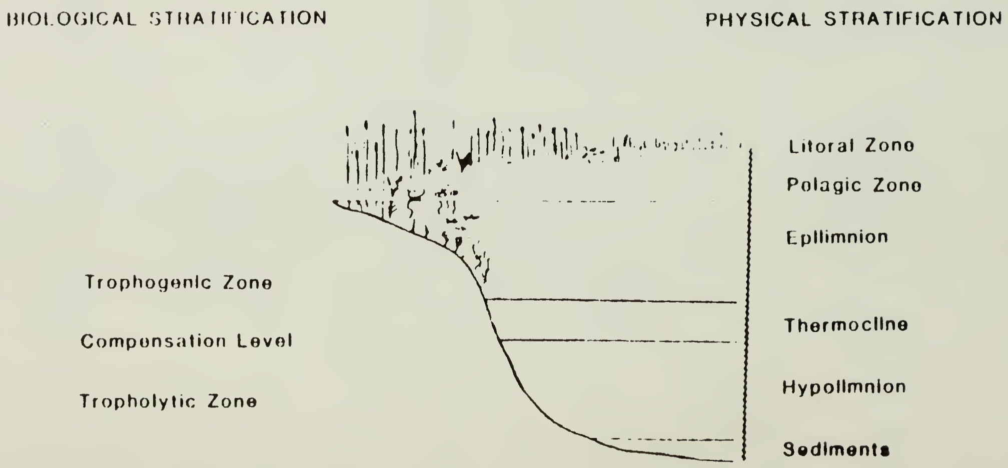
To understand which management practice(s) is/are most appropriate for a given lake, it is necessary to grasp the fundamentals of lake dynamics and ecology.

An unmanaged lake does not stay a lake forever. Through a process called succession, it gradually fills in to become a pond and eventually a meadow. Eutrophication refers to the increased productivity arising from this aging process. A eutrophying lake is characterized by high levels of aquatic vascular plants and/or algae, and increased buildup of bottom sediments. Several factors are responsible, the most important being increased exposure to light and nutrients. Of the latter, phosphorus supply is the stimulus most frequently implicated in increased biological productivity.

Because light, oxygen and nutrients are not equally available throughout the lake, the biological response varies along at least 2 gradients (Fig 1). On a horizontal plane there are two zones - the littoral zone, which is the shallow shore perimeter supporting rooted vegetation; and the pelagic zone, which is the deeper central area. In a vertical section, the lake can be further stratified into 3 temperature-induced density layers. Because the littoral zone usually has a uniform temperature at any given time, it is composed of only one layer. Since light is not limiting, nutrients - especially phosphorus - dictate the intensity of biological activity. Planktonic algae must draw their nutrients from the water, but the rooted aquatic plants derive theirs primarily from the lake bottom.

In the pelagic zone, quite a different environment pertains. Because the water is deeper, it is usually stratified into 3 layers of different temperatures during late summer and winter. The denser, bottom layer (the hypolimnion) has a remarkably constant low temperature throughout the year. The top exposed layer (the epilimnion), reflects the ambient air temperatures through the mixing action of wind, rain and convection currents. The thin middle layer (the thermocline) is defined by a rapid temperature transition between the other two layers. This physical stratification sets the stage for a biological stratification in which the productive photosynthetically active layer (trophogenic) overlies a zone (tropholytic) of nutrient rich decomposition where respiration predominates. In the lower area, light and oxygen are limiting factors, and thus serve as controls in the growth of vegetation. While phosphorus is available (enhanced solubility under anaerobic conditions), the only life capable of exploiting it are the anaerobic and near anaerobic benthic microbiota that tolerate a reduced environment. The upper stratum, however, is much like the littoral zone. There is an abundance of light and oxygen, but phosphorus is, once again, the controlling factor which limits algae, floating plants and the overlying food web. The enriched phosphorus

Lake Zonation



concentration of the lower stratum is unavailable to the trophogenic zone except at turnover when the lake mixes. In New England this happens in the spring and fall, when the water temperature becomes more uniform and thermal stratification is overcome by wind and rain-induced turbulence. Even then, the availability of the phosphorus is short-lived because with mixing, the water becomes oxygenated and the phosphorus is sedimented out.

Normally, a deep lake ages very slowly, filling in a few millimeters a year. This is because the littoral area is relatively small, widely separated from the center, and dwarfed by the tropholytic zone. Plants that die in the outer circumference of the water body, drift towards the middle before they settle out preparing the substrate for the sequence of rooted floating and then emergent vegetation. This filling-in process permits a gradual encroachment of the rooted vegetation into the pelagic zone. In the latter phase of succession, this buildup permits sufficient light into the nutrient rich tropholytic zone to support photosynthesis and, as well, more frequent turnovers. It is at this point that productivity and consequently sedimentation, increase exponentially. The entire lake becomes densely infested with aquatic weeds or algae. It has evolved to a hypereutrophic state.

A CASE STUDY

The pertinence of the preceding discussion can be seen more clearly when the analysis is applied to a specific case. In the spring of 1982 the Beaver Lake Homeowners Association contacted the University of Massachusetts to undertake a study regarding the causes and controls of nuisance aquatic weeds. To define the problem, a three-step procedure was undertaken: assessment, diagnosis and treatment.

Assessment Phase:

The assessment phase involved a search for the stimulus causing eutrophication. Beaver Lake was found to be a thermally unstratified, totally oxygenated water body, with an average depth of 2.4 m. In the aquatic environment the two elements which most often act as limiting nutrients are phosphorus and nitrogen. When neither of these are in short supply, plant growth goes on practically unchecked.

Nitrogen did not appear to present a pollution problem in Beaver Lake. Moderate quantities of it entered through the inflow, ground water and rain in the forms of ammonia and nitrate. These two compounds are very soluble and are produced, as well, by nitrogen fixing blue-green algae. Nitrogen is rarely in limiting quantities except in grossly polluted lakes. Phosphorus, on the other hand, is virtually insoluble in oxygenated waters. Further, because it is readily adsorbed to clays/mud and humate colloids, it is usually in short supply except in the muds. The fact that algal blooms were rare, that rooted macrophytes grew densely, and that nutrients were very low in the water column, implicated phosphorus.

Diagnoses:

Assuming the critical stimulus was sediment phosphorus, the next question addressed was how did it come to concentrate and subsequently cycle there. All significant external and internal inputs, as well as reservoirs of phosphorus in the lake had to be quantified.

The data were generated in a three stage sequence:

1) The first level of inquiry was to measure external loading. Sources of the nutrient were the inflow, ground water and rain. Phosphate concentrations of ground water were determined in well samples collected at six points around the lake perimeter. Inflow and collected rain sample measurements were made periodically throughout the fall. The outflow of nutrients was estimated in a manner similar to inflow determinations.

2) The assessment of the internal PO_4 budget was confined to

two of the major loading sources which provide a good measure of the entering phosphorus. The first was lake internal loading originating from decaying plant matter. To quantify the rate of total phosphate released, white water lily was transferred from the lake to a bucket containing five liters of lake water. Total phosphate was measured at the beginning of the experiment, and weekly for two months thereafter, until the value stabilized at its maximum level. (It must be noted here that the white water lily is not the single dominant species). This number, although a gross approximation, yields an indication of the relative importance of macrophyte decay to the phosphorus budget. The second internal source is ground water welling up through the sediments. Well water was percolated through four 10-centimeter-long cylindrical mud cores at rates of 2.5 ml/hour, 2 ml/hour, and 10 ml/hour. The water was then analyzed for phosphorus content. A correction factor for the amount of this nutrient initially present was subtractted.

3. The third stage of the phosphorus budget was devoted to quantifying the amount of phosphorus existing in the water, sediments and macrophytes. An average value of phosphorus concentration in mg/l of water was extrapolated to mg/lake by multiplying the concentration of phosphorus by the lake volume. A value for sediment total phosphorus was obtained by digesting a known quantity of the mud. This value was used to estimate the total phosphorus supply in the active sediments. Finally, a variety of plants were cut at the sediment-water interface. They were then dried, weighed and analyzed for phosphorus content. Leaves and stems were studied separately where possible. The experiment involved total phosphorus measurements of three species of macrophytes. The results were used to estimate total phosphate plant values for the entire lake from estimated plant densities.

THE PHOSPHATE BUDGET

Beaver Lake is fed mainly by the pristine, nutrient-poor waters of the Quabbin reservoir, as well as ground water. These sources provide inflow to the water body through both surface flow (Beaver Brook) and subsurface groundwater seepage. Approximately 21.5 kg/yr of nutrient entered by way of surface inflow (accounting for 71% of the external inputs), while only 0.49 kg/yr (1.5%) entered via the groundwater. A third source, atmospheric percipitation, accounts for 8.31 kg/yr (27.5% of the external load). The annual outflow of 23.7 kg/yr largely counterbalances the total inflow (30.3 kg/yr); the net nutrient gain to the lake, therefore, was 6.6 kg/yr. In other words, 13.5 mg/m^2/year of total phosphorous accumulated in the lake due to external inputs. This loading accounts for ∿13% of the total phosphorus extering the water column each year, and is far below the critical eutrophic limit of 199.8 mg/m^2/year for Beaver Lake (E. B. Welch, 1980). In point of fact, when the external nutrient budget is considered alone, the lake is oligotrophic.

It is internal loading of total phosphorus from dying plants and groundwater percolation which accounts for the other ∿87% of the loading. For Beaver Lake, the total phosphorus loading from this source was 89 kg/year. Landers (1979) showed water milfoil to be a major source of nutrients to the water column during late summer dieback. Welch (1979) substantiated the importance of dieback of aquatic plants to nutrient loading of the water column also, by describing an increase in the phosphorus water concentration at this time to 69 mg/l from a winter value of 45 mg/l. The value calculated for the internal loading due to groundwater percolation through the sediments was 20 kg/yr (approximately 18% of the internal load). Under anaerobic conditions, phosphorus which was bound to the surface of the clay particles becomes soluble. Welch (1980) generalized that the release of this nutrient under anaerobic conditions is ten times greater at the sediment surface then when oxygenated. Kelderman disputes this however. His findings for Lake Grevelingen revealed only a doubling of the release rate due to anoxia (1980).

The major phosphorus loss in the internal system is sedimentation. Five buckets were placed in Beaver Lake for 6 months to measure this variable. Chemical analysis of the sediment collected provided the basis for estimating the sedimentation rate at 38.2 kg/year. When this value is subtracted from the summed internal loaders, there is a net gain of 70.8 kg/year. That is, approximately 141.6 mg/m(2)/year of total phosphorus are available to the water column due to internal loading. This factor, by itself, raises Beaver Lake to a mesotrophic level and increases loading to a total value of 155.1 mg/m(2)/year. As a consequence, the principal source of total phosphorus to the water column is internal loading, primarily through macrophyte dieback. Since there are few algal blooms as yet, and little phosphorus in the water column, the phosphorus here is not of concern. Most of it is sedimented out due to the oxygenated water. The reservoirs of critical significance are the aquatic plants. It must be determined how much phosphorus they contain, their relationship to the sediments, and their capacity to provide phosphorus to the water column.

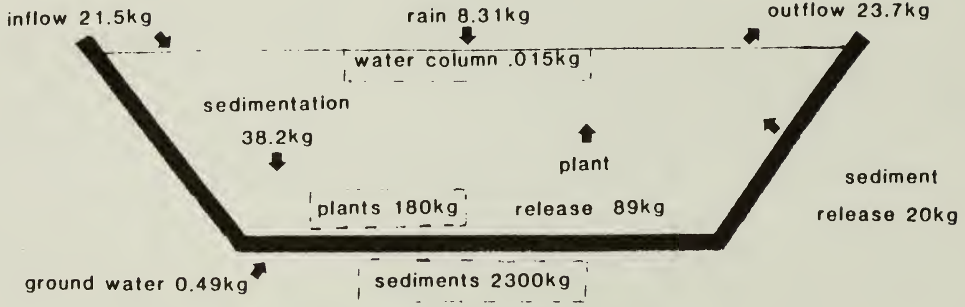
The submergent aquatic weeds of Beaver Lake derive at least 70% of their phosphorus supply from the sediment, with emergent and floating varities also using the muds as a major source of nutrients. Carignan and Kaliff (Loucks, 1979) asserted that 70% to 100% of rooted water milfoil phosphorus content originated from the sediment, and presented conclusions which are very similar for other heavily rooted species. In Lake Wingra, measurements for milfoil showed that 74% of the plants' uptake of this nutrient was from the sediments (Louck, 1979). Finally, Elodea densa in Long Lake in Washington was shown to draw up to 85% of its phosphorus needs from the muds (Loucks, 1979). The other 15% or so of macrophyte nutrients came from the water column which, in Beaver Lake, contains .015 kg of phosphorus at any one time , 98.5% of which is still in the particulate form (Lean, 1973).

The total aquatic macrophyte community has a phosphorus content of 180 kg. This makes them a secondary nutrient sink. When they dieback they release approximately 89 kg to the water column which quickly returns to the muds. The muds, then, act as the major nutrient sink (2300 kg P). This cycled phosphorus thus remains available as a nutrient source for future use by macrophytes. The sediment phosphorus is the ultimate source of all internal cycling. To prevent future macrophyte growth, either the availability of sediment phosphorus to the macrophytes must somehow be prevented, or some other critical factor such as light must be reduced.

Sediment is invariably deposited in lakes, and mostly at the mouths of the tributaries, resulting in delta formation. The muds of Beaver Lake, however, are 2m deep at the inflow, and .10 to .30m meters elsewhere. The large accumulation most likely resulted from two operations within the watershed. The first was an oak mill that was operated on the western side of the lake from 1968 to 1970, and the second was a clear-cutting operation that occurred in 1979 and 1980 . Both of these projects involved heavy truck traffic (Ahearn, 1982). As a result, the denuded soil was destablilized because there was nothing to bind it together. Vegetation favors infiltration of rain water and stabilizes the earth from erosion by water and wind (Allison and Palmer, 1980). During heavy rains, these phosphorus-rich organics travelled into Beaver Lake directly by overland flow, or via Beaver Brook. Soil erosion is, in fact, one of the largest sources of pollution (Miller, 1978).

RESULTS

ANNUAL PHOSPHATE EXTERNAL / INTERNAL LOADING BUDGET



EXTERNAL BUDGET

[Inflow (71%) + Rain (27.5%) + Ground Water (1.5%)] – Outflow = External Budget

[21.5kg + 8.31kg + 0.49kg] – 23.7kg = 6.6kg = 13.5 mg/m^2yr

INTERNAL BUDGET

[Plant Decay (82%) + Mobilization from Sediments (18%)] - Sedimentation = Internal Budget

[89kg + 20kg] – 38.2kg = 70.8kg = 141.6 mg/m^2yr

TOTAL LOADING = 77.4kg = 155.1 mg/m^2yr

EUTROPHIC LOADING LIMIT (Vollenweider) 199.8 mg/m^2yr ∴ MESOTROPHIC

CONCLUSION

Treatment:

A multipurpose in-lake management strategy would probably best serve Beaver Lake. Since the water body has a controllable outflow weir, this could be readjusted to allow more water to flow out during the winter. The littoral plants would be exposed to freezing, and the sediments would be compacted. This latter process would serve to deepen the lake, and could restrict the number of turnovers causing a reduction in the supply of nutrients to the water column. As a result, the possibility of algal blooms would be reduced. The process of overwinter drawdown would be effective with the species of plants colonizing Beaver Lake. Though this practice will only impact those macrophytes in the littoral zone, these major dense problem areas could be dramatically reduced in a cost effective fashion. Where the shorter plants at the middle region are causing concern, polyethylene shading could be applied.

In summary, it must be noted that the problem with Beaver Lake was most likely caused by poor watershed management practices. The technology exists to amelioriate runaway lake productivity. For the remedial measures to be long lasting, however, this watershed must be protected from unnecessary external loading.

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